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Attorney Docket No. TI-31011

Assistant Commissioner for Patents
Washington, D. C. 20231

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Judy Moody

Sir:

Transmitted herewith for filing is the patent application of:

Inventor(s): Abdellatif Bellaouar

For: **Using An IF Synthesizer To Provide Raster Component Of Frequency Channel Spacing**

Enclosed are:

7 sheets of drawings and 21 pages of Specification (including Abstract)
X Declaration/Power of Attorney
X Assignment with form PTO 1595

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	NUMBER		**NUMBER EXTRA**	**RATE**	**BASIC FEE $ 710.00**
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102521-00052- 2499125.1

USING AN IF SYNTHESIZER TO PROVIDE RASTER COMPONENT OF FREQUENCY CHANNEL SPACING

FIELD OF THE INVENTION

The invention relates generally to radio frequency communications and, more particularly, to frequency channel spacing in radio frequency communications.

BACKGROUND OF THE INVENTION

In some radio frequency (RF) communication systems, the channel spacing for the transmitter can be, for example, 5 MHz with a 200 KHz raster. This means that the channel spacing is as follows:

$$\Delta f_{channel} = 5 \pm n \text{ x } 0.2 \text{ MHz},$$

Where n is a small integer number. Thus, the channel spacing can be, for example, 4.6 MHz, 4.8 MHz, 5.0 MHz, 5.2 MHz, etc. Examples of RF systems that use such channel spacing include WCDMA systems and UMTS systems.

FIGURE 1 diagrammatically illustrates a conventional example of an architecture for producing an output transmit frequency f_{TX} having a desired channel spacing dependent upon the desired raster, for example, the channel spacing defined in the foregoing equation. In the example of FIGURE 1, a baseband signal 11 is input to an intermediate frequency (IF) processing section 12 where it is combined with a signal 13 produced by a frequency synthesizer 14. The signal 13 has a frequency f_{LO} (IF) that, when combined with the baseband signal 11 produces an IF signal 15. In the conventional example of FIGURE 1, the frequency of the signal 13 is a fixed frequency. The IF signal 15 is input to an RF processing section 16, where it is combined with a signal 17 produced by a frequency synthesizer 18. The RF processing section 16 produces at 19 an output frequency f_{TX} having the desired channel spacing. The signal 17 output from the frequency synthesizer 18 has a frequency designated in FIGURE 1 as f_{LO} (RF). The frequency synthesizer 18 has raster capability which provides the desired channel spacing in the output frequency f_{TX}.

FIGURE 2 diagrammatically illustrates one example of the conventional frequency synthesizer 18 of FIGURE 1, namely an integer phase locked loop (PLL) example. In the example of FIGURE 2, a comparison frequency generator includes an oscillator 21 and a divider 23. The oscillator 21 provides a frequency reference 22 which is applied to a divider 23 that divides the frequency reference by a divisor R to produce at 24 a comparison frequency of 200 KHz. This 200 KHz comparison frequency corresponds to a desired 200 KHz raster. A divider 25 divides the output signal 17 by a divisor N in order to obtain at 26 another 200 KHz signal. The remaining components of FIGURE 2, namely the frequency generator 27, the phase detector 28, the charge pump 29 and the loop filter 30 are well known in the PLL art, both structurally and functionally, and will therefore not be described in further detail.

In the example of FIGURE 2, in order to achieve the desired 200 KHz raster, the comparison frequency at 24 must be set to 200 KHz, which also requires the divider 25 to produce a 200 KHz signal at 26. This requirement of producing a 200 KHz signal can cause the divisor N of the divider 25 to be a large number. For example, and referring also to FIGURE 1, if the IF signal at 15 has a frequency of 400 MHz and the frequency f_{TX} ranges from 1,920 to 1,980 MHz, then the frequency f_{LO} (RF) can be as high as 2,320 to 2,380 MHz when utilizing high-mode injection. Under these circumstances, the

feedback divisor N would need to be nearly 12,000 in order to generate the 200 KHz frequency at 26. Such a large divisor N can disadvantageously result in high phase noise and therefore a large RMS phase error, and can also result in a disadvantageously slow lock time for the channel selection.

FIGURE 3 diagrammatically illustrates another conventional PLL example of the frequency synthesizer 18 of FIGURE 1. The synthesizer of FIGURE 3 is a so-called fractional synthesizer, which is well known in the art. For larger values of M, such as M=8, the fractional frequency synthesizer can produce frequencies in the aforementioned range of 2,320 – 2,380 MHz with a divisor N having a value of less than 1,500. Thus, the fractional synthesizer has the advantages of a relatively low feedback divisor N' and thus good phase performance, and a relatively fast lock time, particularly if the oscillator is pre-tuned. However, fractional synthesizers such as shown in FIGURE 3 have the inherent disadvantage of fractional spurs, as well as the disadvantage of requiring a large capacitor in the loop filter, particularly for smaller values of the divisor N. The large capacitor is particularly disadvantageous if the frequency synthesizer is intended to be fully integrated.

It is therefore desirable in view of the foregoing to provide for synthesizing frequency channel spacing without the aforementioned disadvantages associated with conventional approaches.

In the synthesis of frequency channel spacing according to the present invention, the desired raster is advantageously provided by an integer IF frequency synthesizer. The frequencies associated with the IF synthesizer are lower than those associated with an RF synthesizer, so a lower feedback divisor can be used to provide the comparison frequency associated with the desired raster. Because the raster is provided for in the IF synthesizer, the RF synthesizer can advantageously utilize a higher comparison frequency (and a correspondingly lower feedback divisor) than in prior art systems.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 diagrammatically illustrates a conventional apparatus for producing an RF signal from a baseband signal.

FIGURE 2 diagrammatically illustrates a conventional example of a frequency synthesizer in FIGURE 1.

FIGURE 3 diagrammatically illustrates another conventional example of a frequency synthesizer in FIGURE 1.

FIGURE 4 diagrammatically illustrates a transmitter apparatus for producing an RF signal from a baseband signal according to the invention.

FIGURE 5 diagrammatically illustrates an exemplary embodiment of the IF frequency synthesizer of FIGURE 4.

FIGURE 6 diagrammatically illustrates an exemplary embodiment of the RF frequency synthesizer of FIGURE 4.

FIGURE 7 diagrammatically illustrates pertinent portions of an exemplary embodiment of the IF processing stage of FIGURE 4.

FIGURE 8 diagrammatically illustrates pertinent portions of an exemplary embodiment of the RF processing stage of FIGURE 4.

FIGURE 9 diagrammatically illustrates another transmitter apparatus according to the invention for producing an RF signal from a baseband signal.

FIGURE 10 is a spectral diagram which graphically illustrates signals used in the apparatus of FIGURE 9.

FIGURE 11 illustrates exemplary operations which can be performed by the embodiments of FIGUREs 4-8.

FIGURE 12 illustrates exemplary operations which can be performed by the embodiments of FIGURES 4-10.

DETAILED DESCRIPTION

FIGURE 4 diagrammatically illustrates pertinent portions of an exemplary transmitter apparatus (e.g. WCDMA or UMTS) for converting a baseband signal into an RF transmission signal according to the invention. In the exemplary apparatus of FIGURE 4, a baseband signal 41 is input to an IF processing section 42 which combines the baseband signal with a further signal 43 produced by an IF frequency synthesizer 44. The signal 43 is provided at a frequency f_{LO} (IF). At 45, the IF processing stage 42 outputs an IF signal to an RF processing stage 46 which combines the IF signal 45 with a further signal 47 produced by an RF frequency synthesizer 48. The signal 47 has a frequency designated in FIGURE 4 as f_{LO} (RF). The RF processing section 46 outputs at 49 an RF transmission signal at a frequency f_{TX} having a desired channel spacing, for example, 5 ± n x 0.2 MHz.

According to the present invention, the IF frequency synthesizer 44 of FIGURE 4 includes the rastering capability that is conventionally provided in RF frequency synthesizers (see, for example, 18 in FIGURE 1). Because the frequency f_{LO} (IF) of the signal 43 produced by the IF frequency synthesizer 44 is substantially lower than the frequency f_{LO} (RF) of the signal 47 produced by the RF frequency synthesizer 48, the IF frequency synthesizer 44 can be advantageously used to provide the desired raster

without requiring an undesirably large feedback divisor to produce the comparison frequency (which corresponds to the desired raster). Furthermore, because the raster is provided by the IF frequency synthesizer 44, the RF frequency synthesizer 48 can use any comparison frequency (designated as $f_{compare}$ in FIGURE 4) that is greater than the desired raster.

FIGURE 5 diagrammatically illustrates an exemplary embodiment of the IF frequency synthesizer 44 of FIGURE 4. The embodiment of FIGURE 5 is an integer PLL frequency synthesizer that provides a 200 KHz raster with a feedback divisor of N=2,000 and a 0.4 MHz comparison frequency at 54. Assuming N=2,000, if the divider at 52 divides by 4 (instead of 2 as illustrated), then the comparison frequency at 54 will be 0.8 MHz. As another example, if the divider 52 is eliminated from FIGURE 5, then the comparison frequency at 54 would be 0.2 MHz (for a value of N=2,000). Note that the embodiment of FIGURE 5 has a type-1 PLL structure wherein the phase detector 58 is coupled to the loop filter 30 without use of a charge pump. This type-1 structure, which is well-known in the art, can advantageously reduce the capacitor values in the loop filter.

FIGURE 6 diagrammatically illustrates an exemplary embodiment of the RF frequency synthesizer 48 of FIGURE 4. The frequency synthesizer of FIGURE 6 is an

integer PLL frequency synthesizer. The RF frequency synthesizer of FIGURE 6 uses a 5 MHz comparison frequency at 62 and a typical feedback divisor value of N=470. Referring also to FIGURES 4 and 5, the apparatus of FIGURE 4 can provide the same output frequency (1920 – 1980 MHz) with the same channel spacing (5 ± n x 0.2 MHz) as is provided by the conventional apparatus of FIGURE 1, but using feedback divisors of N=2,000 (in FIGURE 5) and N=470 (in FIGURE 6) instead of the prior art feedback divisor of N=12,000. The respective feedback divisors of the frequency synthesizers 44 and 48 are significantly lower than the feedback divisors associated with prior art arrangements such as shown in FIGURE 1, thus providing improved phase noise performance and faster locking as compared to prior art arrangements. The exemplary frequency synthesizer 48 is also implemented as a type-1 PLL.

If the available oscillator 21 of FIGURE 6 does not permit generation of a 5 MHz comparison frequency at 62 (for example a 13 MHz reference frequency from the oscillator 21 would not permit derivation of a 5 MHz comparison frequency if R is an integer), then another relatively high comparison frequency can be used. For example, with a 13 MHz reference frequency from the oscillator 21, the divider at 23 can derive a 1 MHz comparison frequency at 62 if R=13. With a 1 MHz comparison frequency, the

feedback divisor would have a typical value of N=2,350, which is still significantly lower than the feedback divisors associated with conventional arrangements.

FIGURES 7 and 8 diagrammatically illustrate exemplary embodiments of the IF processing section 42 and the RF processing section 46, respectively. In the embodiment of FIGURE 7, the baseband I and Q signals are input to a conventional IQ modulator 71. The modulator 71 can utilize conventional techniques to combine the signal 43 (see Figure 4) with the baseband I and Q signals to produce an output signal 72 which is applied to a conventional variable gain amplifier (VGA). The output 73 of the VGA is applied to a conventional low-pass filter 74 whose output is coupled to the RF processing section 46 of FIGURE 4.

The embodiment of FIGURE 8 includes a conventional mixer 81 (for example, an SSB mixer or a DSB mixer) which receives the output 45 from the IF processing section 42 (see FIGURE 4). The mixer 81 mixes the IF signal 45 with the signal 47 produced by the RF frequency synthesizer 48 of FIGURE 4. The output 82 of the mixer 81 is provided to a conventional VGA whose output 83 is applied to a conventional power amplifier/driver 84 which provides the output signal 49 of FIGURE 4.

FIGURE 9 illustrates another exemplary apparatus (e.g. WCDMA or UMTS) according to the invention for converting baseband signals into RF transmission signals.

In the exemplary apparatus of FIGURE 9, a modulating digital baseband signal at 91 is applied to a pair of DDS (direct digital synthesizer) sections at 93. The outputs of the DDS sections are input to respective digital-to-analog converters (DACs) to produce baseband I and Q signals also designated as S(f) in FIGURE 9. The I and Q signals are input to respective bandpass filters 95. The outputs of the filters 95 are input to respective VGAs, and the outputs of the VGAs are designated as S'(f) in FIGURE 9. The S'(f) components are input to respective mixers 97 which mix the respective components of S'(f) with a signal W(f) generated by a phase shifter 94. The phase shifter 94 produces the signal W(f) from, for example, the signal 47 produced by the RF frequency synthesizer 48 of FIGURE 6. The outputs of the mixers 97 are combined by a combiner 98 whose output is coupled to a power amplifier/driver 92 that produces a signal R(f). The signal R(f) is input to a bandpass filter 90, for example a SAW filter, that provides an output transmission signal having the frequency f_{TX} and the desired channel spacing. In the arrangement of FIGURE 9, the DDS sections 93 generate the desired (e.g., 200 KHz) raster.

FIGURE 10 illustrates the frequency spectra of the signals S'(f), W(f) and R(f) of FIGURE 9. The signals I and Q corresponding to spectrum S'(f) are provided at a

frequency of f_{IF} ± n x 0.2 MHz, where the "0.2" factor corresponds to the desired raster and the f_{IF} component corresponds to the desired IF frequency.

FIGURE 11 illustrates exemplary operations which can be performed by the embodiments of FIGUREs 4-8. At 110, a signal at frequency f_{LO} (IF) is produced using a comparison frequency corresponding to the desired raster. At 111, a signal at frequency f_{LO} (RF) is produced using a comparison frequency that is greater than the desired raster. At 112, the signal at frequency f_{LO} (IF) is combined with the baseband signal to produce an IF signal and, at 113, the signal at frequency f_{LO} (RF) is combined with the IF signal to produce the desired RF transmission signal.

FIGURE 12 illustrates exemplary operations which can be performed by the embodiments of FIGURES 4-10. At 121, an IF signal, including the desired raster, is produced from the baseband signal. At 122, an RF signal is produced from the IF signal.

It will be evident to workers in the art that the embodiments described above with respect to FIGUREs 4-12 can be readily implemented, for example by suitable modifications in software, hardware, or a combination of software and hardware, in conventional RF transmitters, for example, WCDMA and UMTS transmitters.

Although exemplary embodiments of the invention are described above in detail, this does not limit the scope of the invention, which can be practiced in a variety of embodiments.

WHAT IS CLAIMED IS:

1. An apparatus for producing an RF transmission signal including a plurality of frequency channels, comprising:

an IF processor having a first input for receiving a baseband signal and a second input for receiving a first combining signal, said IF processor for combining the baseband signal with the first combining signal to produce an IF signal;

an RF processor having a first input coupled to said IF processor for receiving the IF signal and a second input for receiving a second combining signal, said RF processor for combining the IF signal with the second combining signal to produce an RF transmission signal including a plurality of frequency channels separated by a desired frequency channel spacing;

a first frequency synthesizer coupled to said second input of said IF processor for providing the first combining signal at one of a plurality of possible frequencies separated from one another by a raster component of said desired frequency channel spacing; and

said first frequency synthesizer including a comparison frequency generator for generating a comparison frequency corresponding to said raster component, said first frequency synthesizer responsive to said comparison frequency for producing the first combining signal.

2. The apparatus of Claim 1, wherein the comparison frequency is an integer multiple of said raster component.

3. The apparatus of Claim 1, wherein the comparison frequency is equal to said raster component.

4. The apparatus of Claim 1, wherein said first frequency synthesizer includes an integer phase locked loop.

5. The apparatus of Claim 4, wherein said phase locked loop is a type –1 phase locked loop.

6. The apparatus of Claim 1, provided in a UMTS transmitter.

7. The apparatus of Claim 1 provided in a WCDMA transmitter.

8. The apparatus of Claim 1, including a second frequency synthesizer coupled to said second input of said RF processor for providing the second combining signal, said second frequency synthesizer including a further comparison frequency generator for generating a further comparison frequency that is greater than said raster component, said second frequency synthesizer responsive to said further comparison frequency for producing the second combining signal.

9. The apparatus of Claim 8, wherein the further comparison frequency corresponds to a further component of said desired frequency channel spacing other than said raster component.

10. The apparatus of Claim 8, wherein said second frequency synthesizer includes an integer phase locked loop.

11. A method for producing an RF transmission signal including a plurality of frequency channels separated by a desired frequency channel spacing, comprising:

providing a first combining signal at one of a plurality of possible frequencies separated from one another by a raster component of the desired frequency channel spacing, including generating a comparison frequency corresponding to said raster component and producing the first combining signal in response to said comparison frequency;

combining the first combining signal with a baseband signal to produce an IF signal; and

combining the IF signal with a second combining signal to produce the RF transmission signal.

12. The method of Claim 11, wherein the comparison frequency is an integer multiple of said raster component.

13. The method of Claim 11, wherein the comparison frequency is equal to said raster component.

14. The method of Claim 11, wherein said providing step includes using an integer phase locked loop to produce the first combining signal.

15. The method of Claim 14, wherein said using step includes using a type-1 phase locked loop to produce the first combining signal.

16. The method of Claim 11, wherein the RF transmission signal is a UMTS transmission signal.

17. The method of Claim 11, wherein the RF transmission signal is a WCDMA transmission signal.

18. The method of Claim 11, including generating a further comparison frequency that is greater than said raster component, and producing the second combining signal in response to said further comparison frequency.

19. The method of Claim 18, wherein the further comparison frequency corresponds to a further component of said desired frequency channel spacing other than said raster component.

20. The method of Claim 18, wherein said step of producing the second combining signal includes using an integer phase locked loop to produce the second combining signal.

21. An apparatus for producing an RF transmission signal including a plurality of frequency channels separated by a desired frequency channel spacing, comprising:

an input for receiving a baseband signal;

an IF processor coupled to said input for receiving said baseband signal and producing therefrom an IF signal including a raster component of said desired frequency channel spacing; and

an RF processor coupled to said IF processor for receiving the IF signal and producing therefrom said RF transmission signal.

22. The apparatus of Claim 21, wherein said IF processor includes a direct digital synthesizer.

23. The apparatus of Claim 21, provided in one of a UMTS transmitter and a WCDMA transmitter.

24. A method for producing an RF transmission signal including a plurality of frequency channels separated by a desired frequency channel spacing, comprising:

producing from a baseband signal an IF signal including a raster component of said desired frequency channel spacing; and

producing the RF transmission signal from the IF signal.

25. The method of Claim 24, wherein the RF transmission signal is one of a UMTS transmission signal and a WCDMA transmission signal.

ABSTRACT OF THE DISCLOSURE

In the synthesis of frequency channel spacing in an RF transmission signal, a raster component of the desired frequency channel spacing is provided by an integer IF frequency synthesizer (44). Because the frequencies associated with the IF synthesizer are lower then those associated with an RF frequency synthesizer (48), the IF synthesizer can incorporate the desired raster using a lower feedback divisor (N) than can the RF synthesizer.

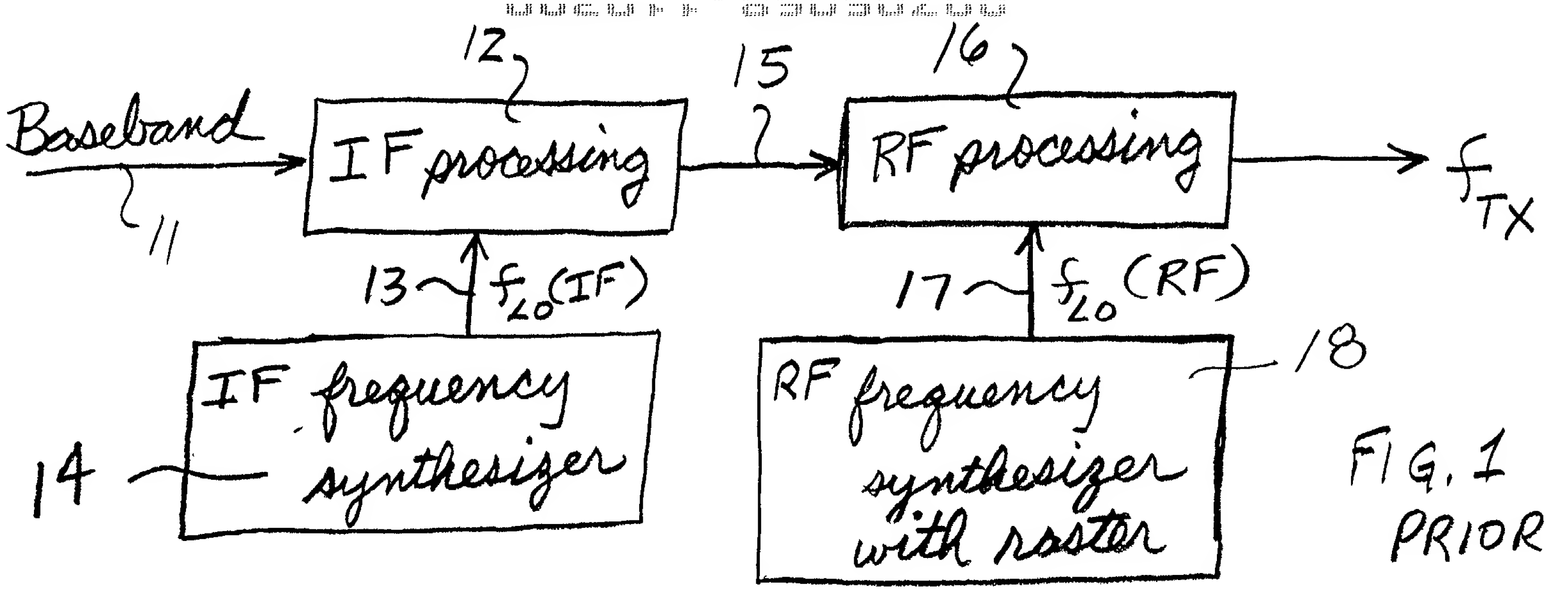


FIG. 1
PRIOR ART

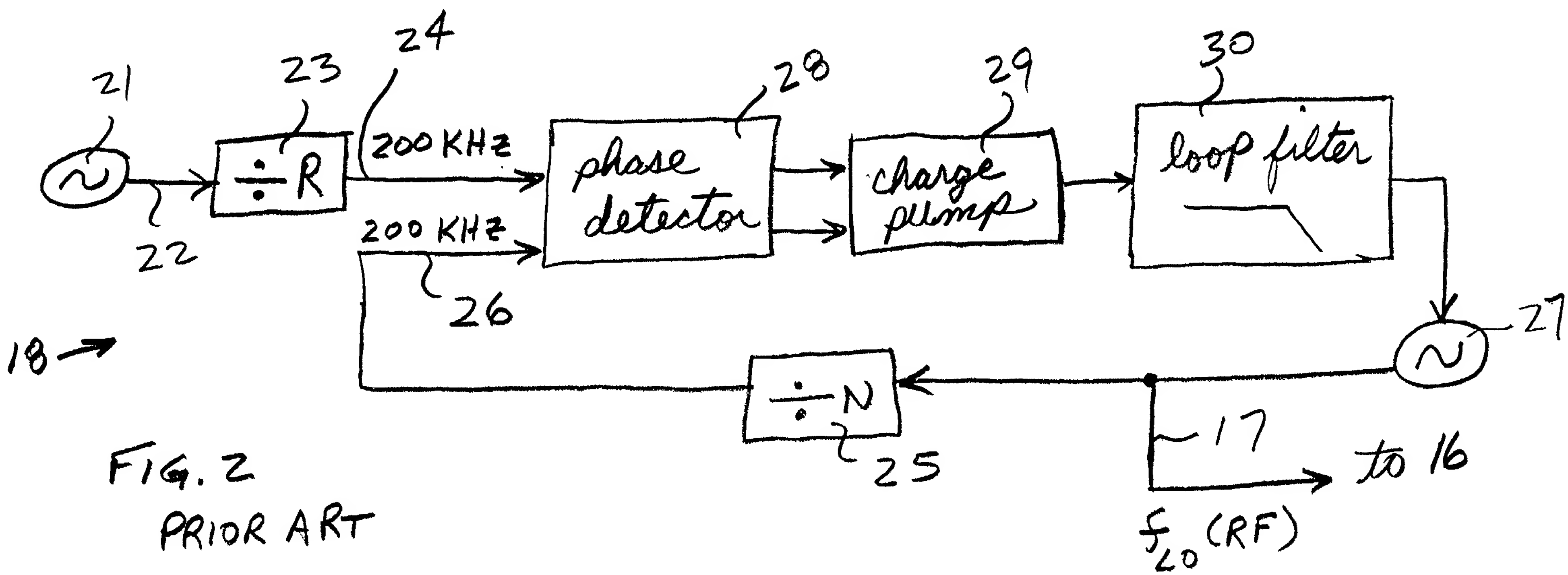


FIG. 2
PRIOR ART

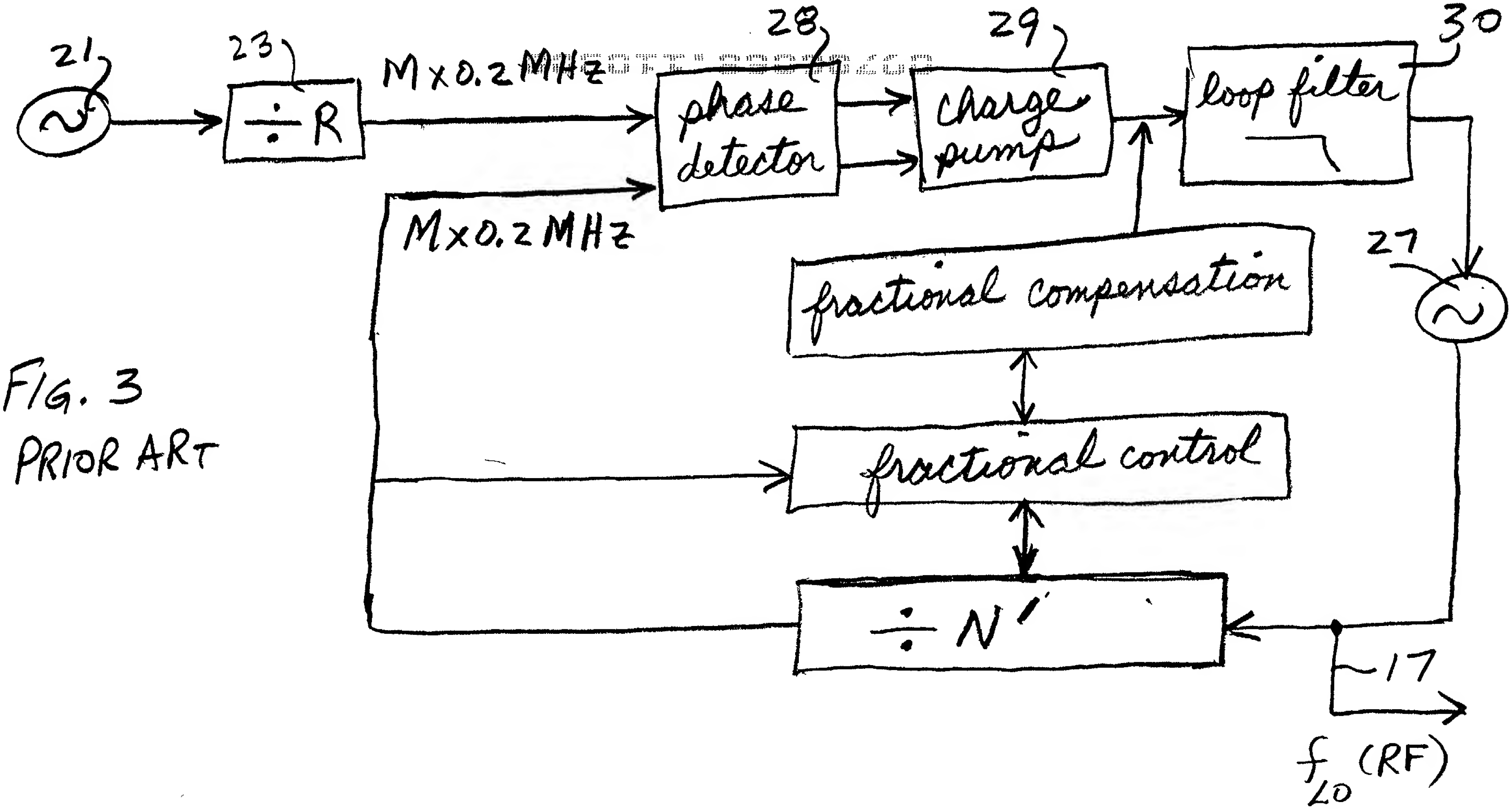


FIG. 3
PRIOR ART

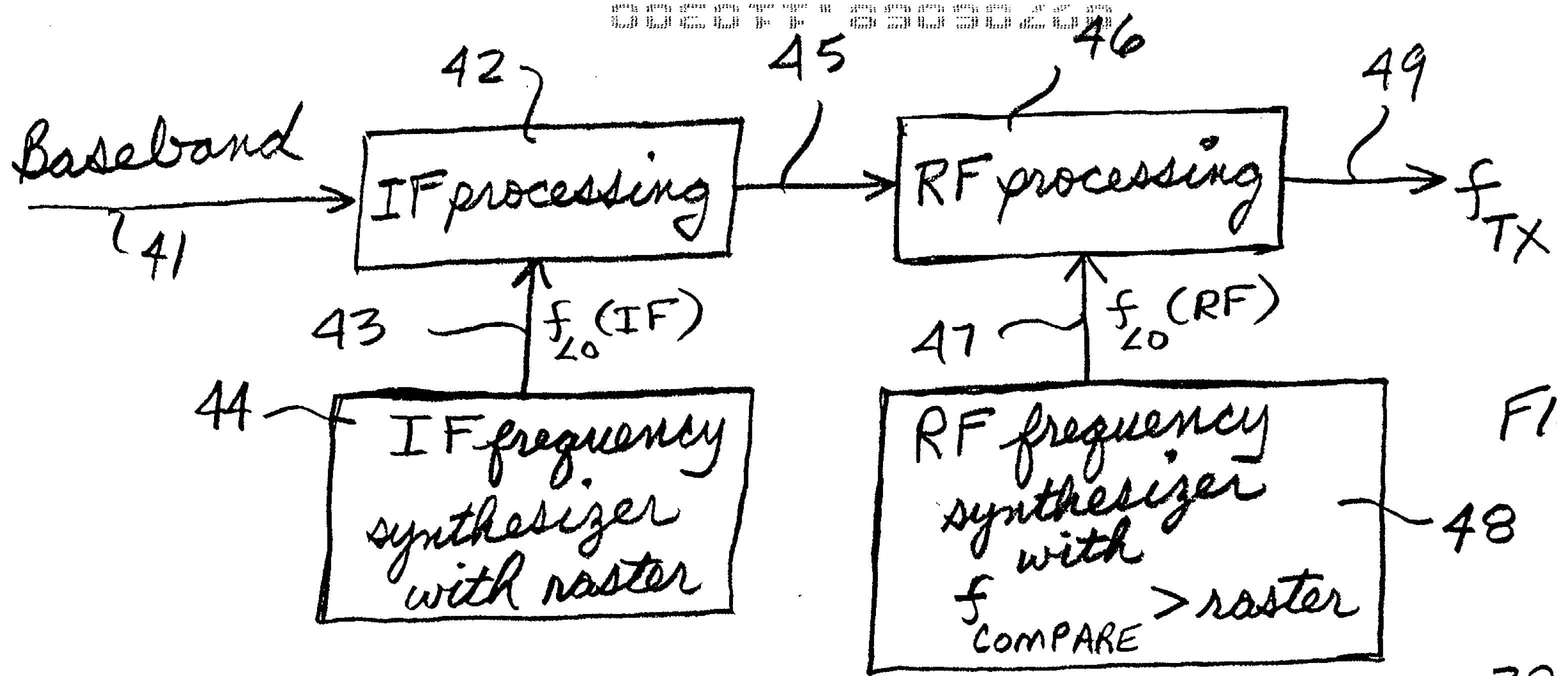

42
45
46
49
Baseband
41
IF processing
RF processing
f_{TX}
43
f_{LO}(IF)
47
f_{LO}(RF)
44
IF frequency synthesizer with raster
RF frequency synthesizer with $f_{COMPARE}$ > raster
48

FIG. 4

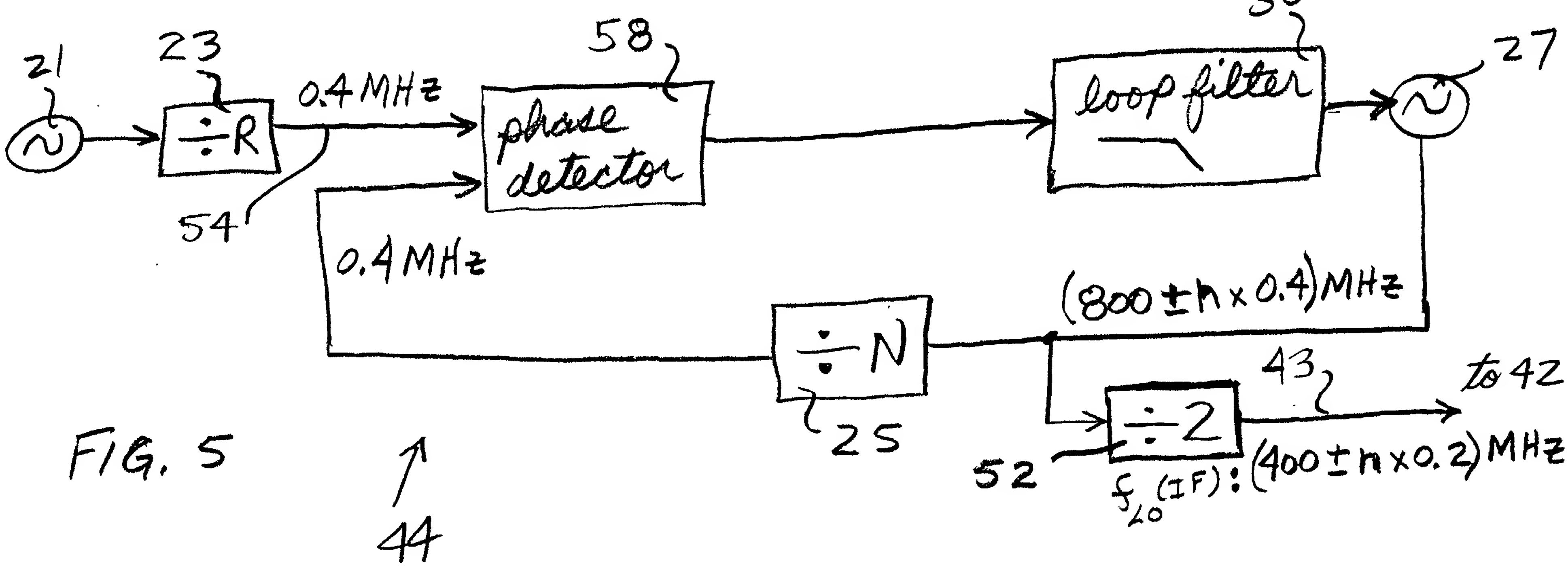

21
23
÷R
0.4 MHz
58
phase detector
30
loop filter
27
54
0.4 MHz
(800 ± n × 0.4) MHz
÷N
25
43
to 42
÷2
52
f_{LO}(IF): (400 ± n × 0.2) MHz
44

FIG. 5

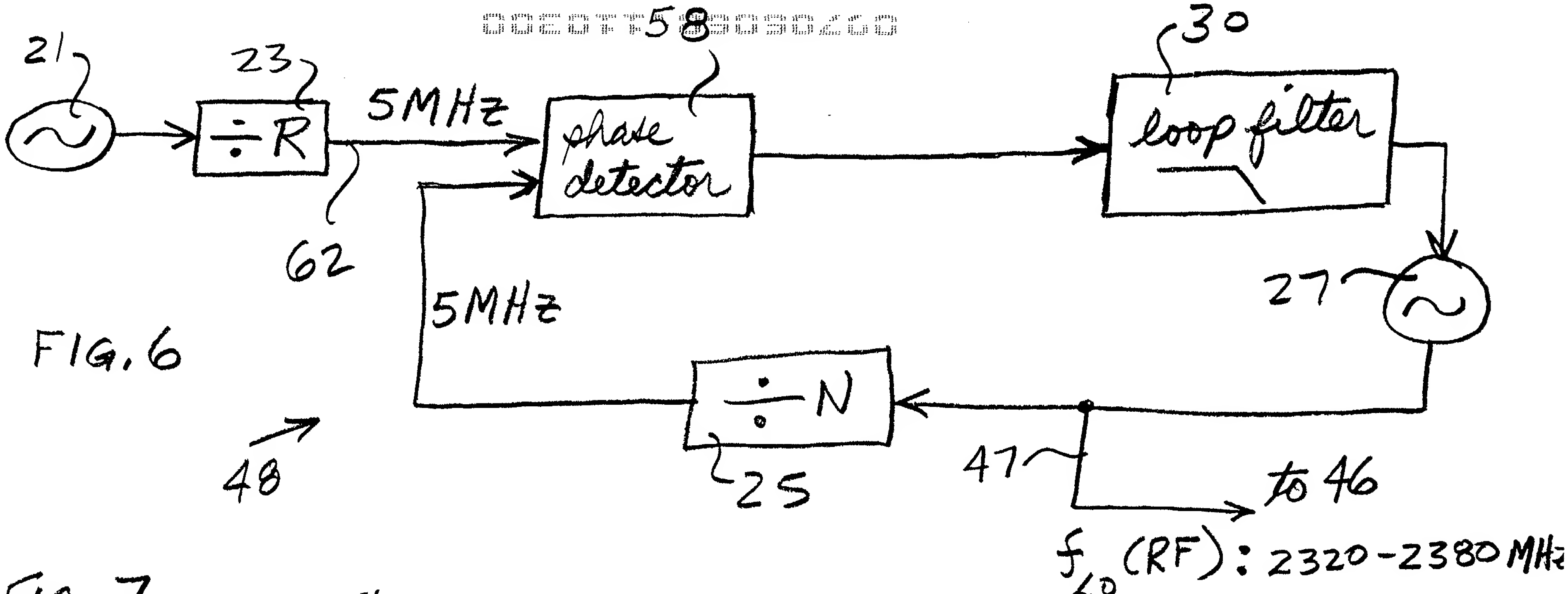
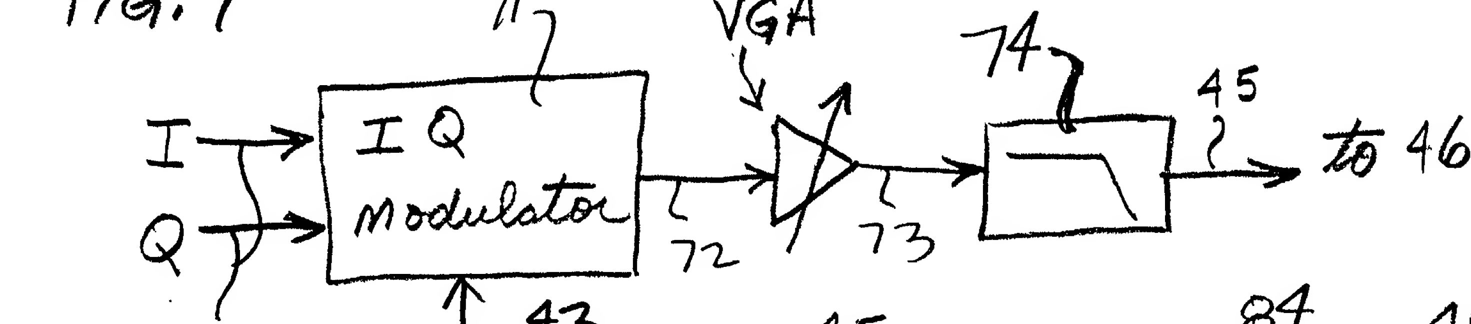


FIG. 6

FIG. 7



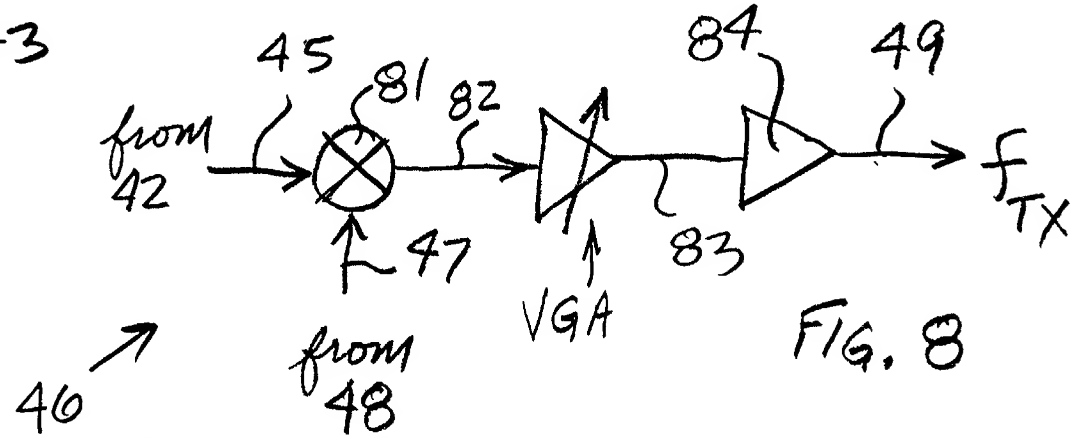
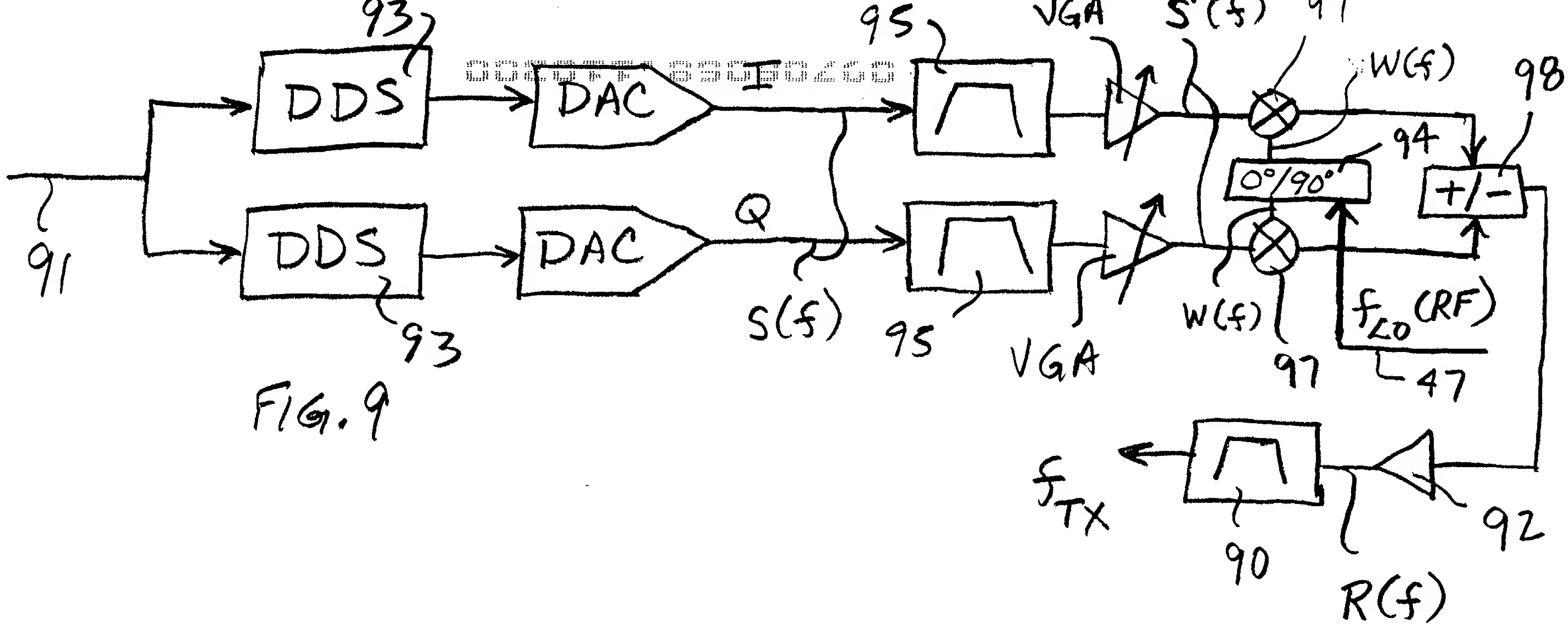
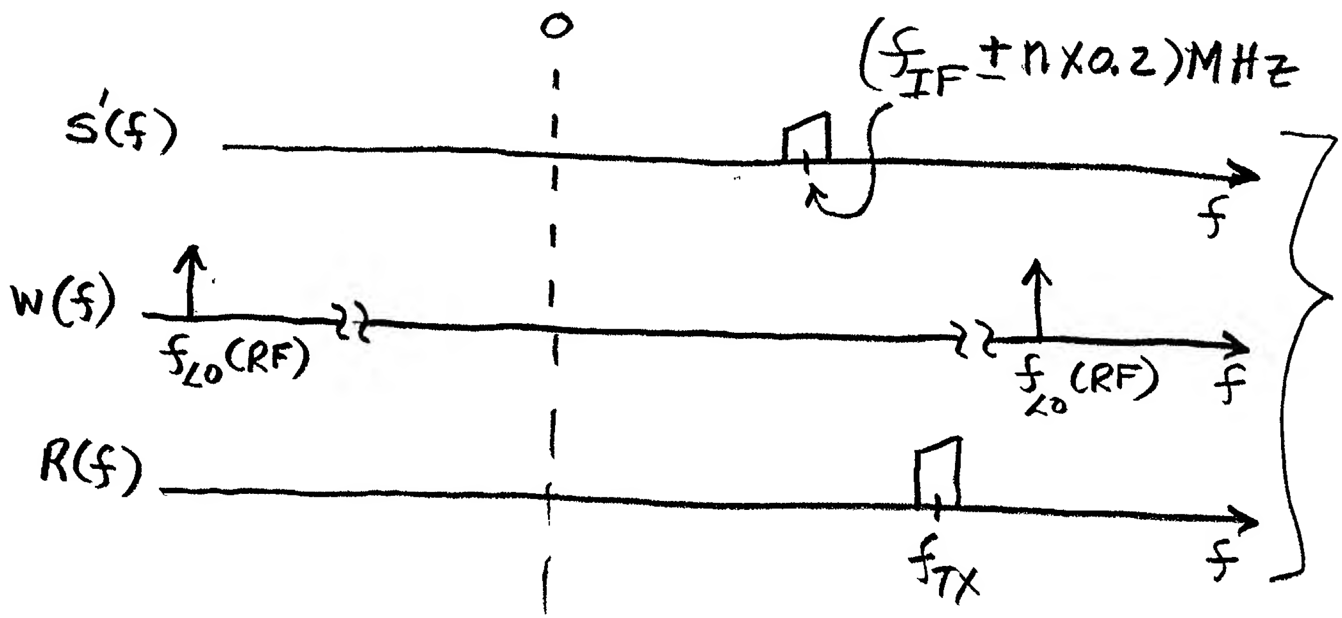


FIG. 8



91
93
DDS
DDS
93
DAC
DAC
I
Q
S(f)
95
95
VGA
VGA
S'(f)
97
W(f)
W(f)
94
0°/90°
97
98
+/−
f_{LO}(RF)
47
92
R(f)
90
f_{TX}

FIG. 9



0
(f_{IF} ± n x 0.2) MHz
S'(f)
f
W(f)
f_{LO}(RF)
f_{LO}(RF)
f
R(f)
f_{TX}
f

FIG. 10

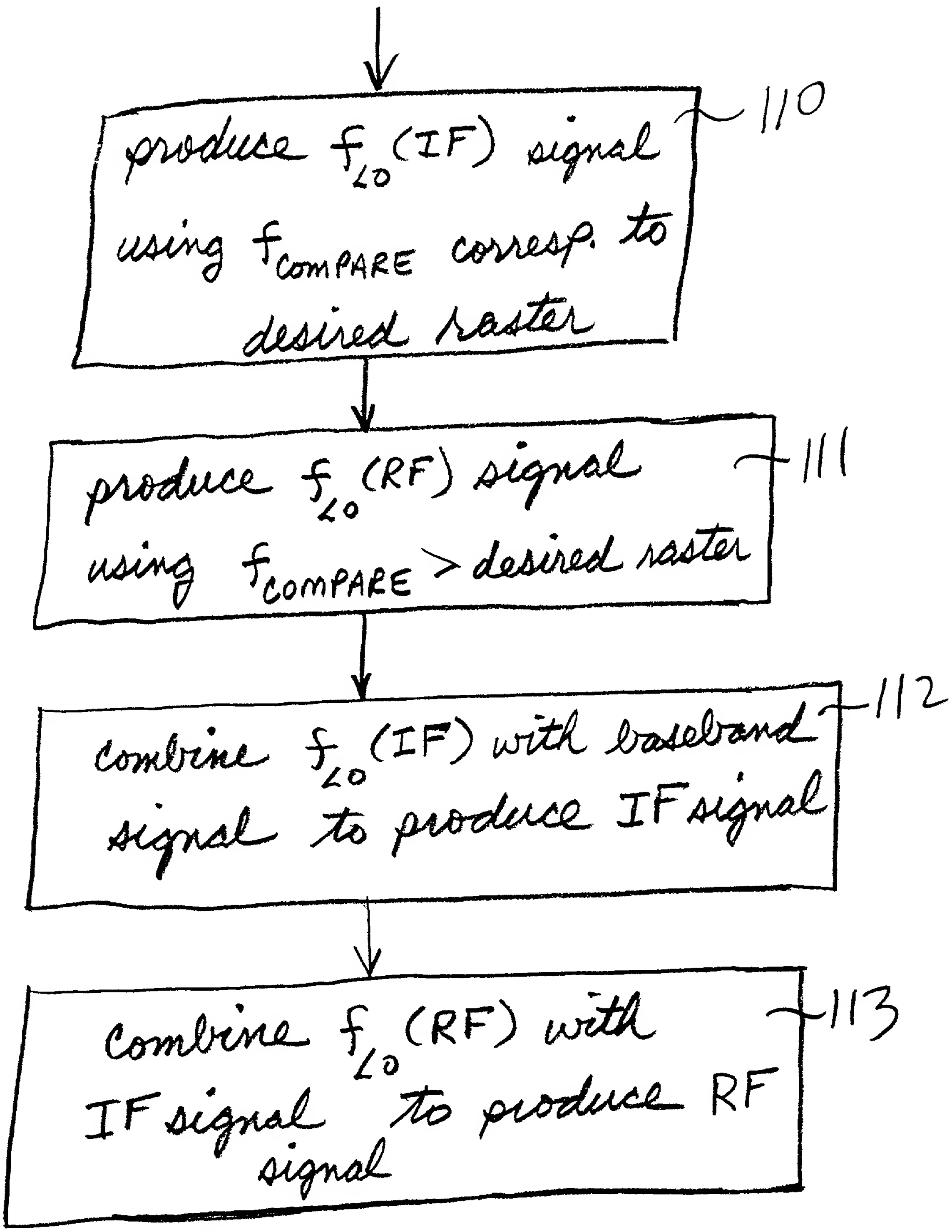

produce f_{LO}(IF) signal using $f_{COMPARE}$ corresp. to desired raster
110
produce f_{LO}(RF) signal using $f_{COMPARE}$ > desired raster
111
combine f_{LO}(IF) with baseband signal to produce IF signal
112
combine f_{LO}(RF) with IF signal to produce RF signal
113

FIG. 11

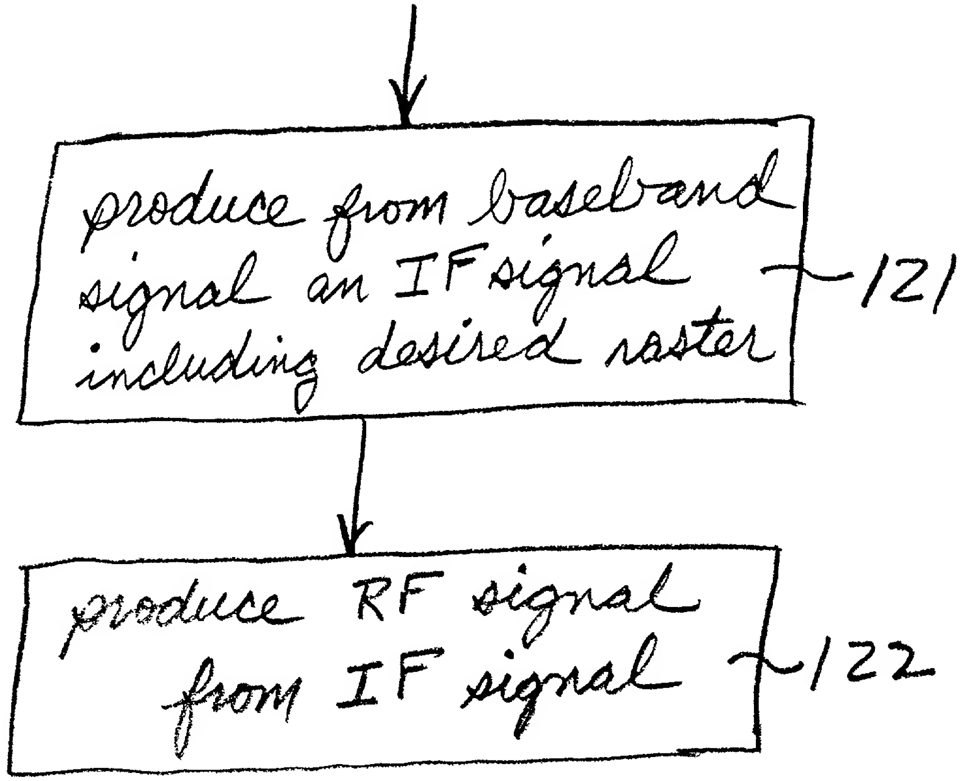

produce from baseband signal an IF signal including desired raster
121
produce RF signal from IF signal
122

FIG. 12

ATTORNEY'S DOCKET NO. TI-31011

APPLICATION FOR UNITED STATES PATENT

DECLARATION AND POWER OF ATTORNEY

As a below named inventor, I declare that my residence, post office address and citizenship are as stated below next to my name; that I verily believe that I am the original, first and sole inventor if only one name is listed below, or an original, first and joint inventor if plural inventors are named below, of the subject matter which is claimed and for which a patent is sought on the invention entitled as set forth below, which is described in the attached specification; that I have reviewed and understand the contents of the specification, including the claims, as amended by any amendment specifically referred to in the oath or declaration; that no application for patent or inventor's certificate on this invention has been filed by me or my legal representatives or assigns in any country foreign to the United States of America; and that I acknowledge my duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, section 1.56(a);

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true, and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

<table>
<tr><td colspan="3">TITLE OF INVENTION: USING AN IF SYNTHESIZER TO PROVIDE RASTER COMPONENT OF FREQUENCY CHANNEL SPACING</td></tr>
<tr><td colspan="3">POWER OF ATTORNEY: I HEREBY APPOINT THE FOLLOWING ATTORNEYS TO PROSECUTE THIS APPLICATION AND TRANSACT ALL BUSINESS IN THE PATENT AND TRADEMARK OFFICE CONNECTED THEREWITH

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Jay Cantor, Reg. No. 19,906
Mark Courtney, Reg. No. 36,491
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Abdellatif Bellaouar</td><td>NAME OF INVENTOR: (2)</td><td>NAME OF INVENTOR: (3)</td></tr>
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Algeria</td><td>COUNTRY OF CITIZENSHIP:</td><td>COUNTRY OF CITIZENSHIP:</td></tr>
<tr><td>SIGNATURE OF INVENTOR:
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X</td><td>SIGNATURE OF INVENTOR:</td><td>SIGNATURE OF INVENTOR:</td></tr>
<tr><td>DATE: November, 02, 2000
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